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Perception of graininess in complex photographic images through objective and subjective comparison

Glenn E. McNeill

PERCEPTION OF GRAININESS IN COMPLEX PHOTOGRAPHIC IMAGES THROUGH OBJECTIVE AND SUBJECTIVE COMPARISON

by

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A thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Science in the school of Photographic Arts and Sciences in the College of Graphic Arts and Photography of the Rochester Institute of Technology

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Submitted to the
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ABSTRACT

A model previously used for the perception of graininess in uniform-density images that exist in electrophotography, has been verified for use in silver-halide photography. In addition, a model has been developed which estimates the sensation of graininess in photographic images of non-uniform density. Given the relationship between graininess and density in uniform-density images, the graininess in a complex image is weighted by the frequency of occurence of each measured density in the image. Such an analysis is compared to subjective evaluations. It is shown that the graininess model is useful in predicting the sensation of graininess in photographs.

Acknowledgement

The author wishes to express special thanks to Mr. Peter Engeldrum whose insights and advice were exceeded only by his support in the completion of this thesis.

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I. Introduction

A review of the literature concerning granularity and graininess has shown that much work has been done on the construction of instruments and the development of techniques for measuring the inhomogeneities in developed silver images.[1-12] The term image noise is used to refer to such inhomogeneities.

The terms granularity and graininess are often misunderstood and sometimes used interchangeably so it becomes necessary to clearly distinguish between the two. Granularity is an objective quantity and is defined by Jones and Higgins[5] as "the spatial variations in transmitting or reflecting characteristics of a developed photographic material." Graininess is the subjective impression of the spatial nonuniformities of the image forming elements in an image.

One of the earliest methods for measuring graininess was the blending distance method used by Jones and Deisch.[6] A procedure was described in which an enlarged image of a uniformly exposed and developed photographic material was moved away from the observer until it appeared homogeneous. The magnification was held constant and a graininess value was established using the relative blending distance as criteria. A similar procedure for measuring graininess was used by Lowry.[7] The method he described consisted of varying the magnification of the image until it appeared homogeneous. The graininess was evaluated as the relative magnification that was needed to produce a homogeneous image.

An objective measurement of noise was described by van Kreveld[8,9,10] and his co-workers. This method considered that the random distribution of grains in photographic materials resulted in density fluctuations. An apparatus was used to measure the density fluctuations and the mean value of the fluctuations was used to evaluate image noise. Each sample used in their experiment was of a constant density. Goetz and Gould[11,12] established a theoretical granularity coefficient to measure the inhomogeneity of photographic emulsions. Six different emulsions were used, each at a constant density. They devised an instrument to measure the granularity coefficient in terms of the standard deviation of the transmittance of the film in question.

Many researchers[5,13-22] have attempted to develop a process which will measure the objective quantity granularity in such a way that it will correlate with the subjective impression of graininess. A series of papers by Jones and Higgins[5,15-22] represents the major work done in this area. The earlier papers are concerned with the characteristics of the human visual system and its implications on graininess and granularity. They introduce an instrument in the fifth paper of the series that is designed to measure graininess in terms of the reciprocal of the blending magnification of a projected image viewed at a constant distance. They also designed a microphotometer for the measurement of granularity. The measurement could be taken in terms of density or transmittance using a circular aperture with a diameter ranging from 1.5 microns to 78 microns.

In the final two papers of their series, they reported that a method had been developed for measuring the granularity of a uniformly exposed and developed photographic deposit that correlated with graininess evaluations. They defined granularity in terms of the diameter of the scanning aperture that would produce the "threshold gradient sensitivity function of the eye for graininess." It was shown that when granularity was defined in such a manner and then multiplied by a constant factor, the resultant was a measurement that correlated with graininess evaluations. This method, however, was limited to measurements of threshold graininess, or in other words, the point at which graininess was just perceptible.

Dooley and Shaw[23] developed a model which estimated graininess in an electrophotographic process. Their paper discusses in depth, the theory of the graininess algorithm developed in their model, the results of which are briefly discussed here. It was their intention to develop an empirical model that would evaluate an objective measurement of image noise in terms that would correlate with a subjective evaluation. If a relationship existed, it would then be possible to predict how the electrophotographic process would be visually judged. The samples used in their experiment were copies of an essentially noise-free step-wedge made on commercial copying machines. The step-wedge produced samples consisting of a series of solid areas which tested the useful range of output density of the copier. The samples were then tested for noise under both objective and subjective conditions to determine if a relationship existed. The objective technique consisted of an algorithm based on Wiener spectrum measurements made on the test samples. The algorithm was designed to predict the human perception of graininess in the test samples. The subjective or psychometric evaluation consisted of observers judging each sample on an arbitrary graininess scale. The predicted graininess from the experimental model was compared to the judged graininess and a 0.97 linear correlation coefficient was established. This experiment demonstrated that it was possible to accurately predict how uniform-density electrophotographic samples would be judged for graininess.

The model developed by Dooley and Shaw only evaluated graininess in uniform-density samples. In addition, all the previously mentioned work consisted of evaluations of image noise in samples of constant density. The question that is raised from the results of Dooley and Shaw is whether such a model can be applied to photographs, which are generally not of constant density. The objective of this investigation, therefore, is to verify the algorithm from the Dooley and

Shaw graininess model for use in uniform-density silver-halide images and to expand its use to predict the graininess in images on non-uniform density.

The hypothesis of this study is that an observer judges the graininess of photographs based on the spatial average of the graininess of the picture. From the graininess algorithm developed by Dooley and Shaw, graininess can be calculated for a wide range of uniform-density images, thus producing a graininess vs. image density curve for a particular imaging system. If a density histogram is produced for an image produced with this imaging system, a graininess value for that image can be calculated by integrating the product of the two functions over the density range of the image. The graininess in a complex image, calculated using this method, is thereby weighted by the fractional area occupied by each density in the image. The graininess value calculated for an image in this manner is hereby defined as the "predicted graininess" for that image.

The predicted graininess can be calculated in this manner for a number of photographic images. Subjective evaluations can then be made on the same photographic images, the hypothesis being that such evaluations would correlate with the predicted graininess values from the graininess model. If a significant correlation were found to exist, it would then be possible to conclude that the graininess model developed in this study is an accurate indicator of the perception of graininess in the photographic process.

II. Experimental

A. Experimental 1 -- uniform-density patches

1. preparation of density patches

In order to generate a series of uniform-density patches that provided a wide range of graininess to test the graininess algorithm, three different films were chosen that differed in their sensitometric characteristics. The three films that were chosen were Kodak Pan-X, Tri-X, and Recording Film 2475. A Kodak Reflectance Gray Scale was photographed with each film using a Nikkormat-FTN 35mm. camera with a 50 mm. Nikkor lens. This produced negatives with a series of uniform-density areas. All films were processed according to manufacturer's recommended conditions.

The film negatives were printed on Kodak Polycontrast Paper at 20X magnification and again, processed to manufacturer's recommended conditions. The magnification was determined such that the graininess for the density patches printed from the recording film negatives was very noticeable and the graininess for those printed from the Pan-X negatives was just noticeable. This resulted in a series of uniform-density patches that exhibited a wide range of graininess. It is important to note that many factors affect the graininess of the density patches including film and paper granularity, film and paper exposing and processing, magnification, and lens-film modulation transfer functions. Remember, however, that the final evaluations of the density patches are made on the finished product. Therefore, precise control over these factors is not a necessity.

2. measurement of Wiener spectrum

The measured Wiener spectrum can be found using the equation[24]

$$WS'(u) = \frac{L\delta x}{n}\left\langle\left|\sum_{x=0}^{N-1}\Delta D'(x)e^{-i2\pi ux}\right|^2\right\rangle \tag{1}$$

where $WS'(u)$ is the measured Wiener spectrum, $\Delta D'(x)$ is the measured density deviation from the mean at some point x, L is the length of the measuring slit, n is the number of density measurements taken at equal spacings δx, u is the spatial frequency at which the Wiener spectrum is calculated.

The effect of the slit width is not directly considered in equation (1) but is a corrupting factor due to its influence on $\Delta D'(x)$ and therefore on $WS'(u)$. The relationship between the actual Wiener spectrum $WS(u)$, and the measured spectrum is[24]

$$WS'(u) = MTF_a^{\,2}(u)\ WS(u) \tag{2}$$

where MTF_a is the transfer function of the overall measuring system. Assuming the microdensitometer optics have a negligible effect, the transfer function of the system is expressed as

$$MTF_a(u) = \frac{\sin(\pi ua)}{\pi ua} \qquad (3)$$

where a is the slit width. Rewriting equation (2) as

$$WS(u) = \frac{WS'(u)}{MTF_a^{\,2}(u)} \qquad (4)$$

and using the results from equation (3) removes the effect of the slit width.

All Wiener spectrum measurements were taken using a Xerox reflection microdensitometer provided by the Xerox Corporation. 23 density patches were chosen, which provided a wide range of graininess and density to test the Dooley and Shaw graininess algorithm. Each density patch was scanned and its Wiener spectrum calculated. The slit dimensions used in scanning were 1000 X 25.4 um. 2000 density readings were taken for each density patch. 40 blocks of 50 digital density readings were taken at a constant sampling interval of 12.7 um. The Wiener spectrum generated from these density patches is shown in appendix A.

3. measurement of graininess -- algorithm

The graininess algorithm developed by Dooley and Shaw is expressed as follows

$$GS = e^{-1.8\bar{D}} \int_0^{\infty} \sqrt{WS(u)}\ VTF(u)du \qquad (5)$$

where WS(u) is the Wiener spectrum, $e^{-1.8\bar{D}}$ is the empirically determined sensitivity function in Fig.1, and VTF(u) is the visual transfer function shown in Fig.2. The graininess was calculated in this manner for each of the 23 density patches produced. The implications of this algorithm are discussed in the paper by Dooley and Shaw. It is sufficient to say that while graininess is a nonlinear function of image density, the spectrum of noise or Wiener spectrum, is highly linear with image density. Therefore, in developing a model for predicting graininess, Dooley and Shaw found it necessary to incorporate in their model not only the noise spectrum, but also a visual response function and a sensitivity or "weighting" function.

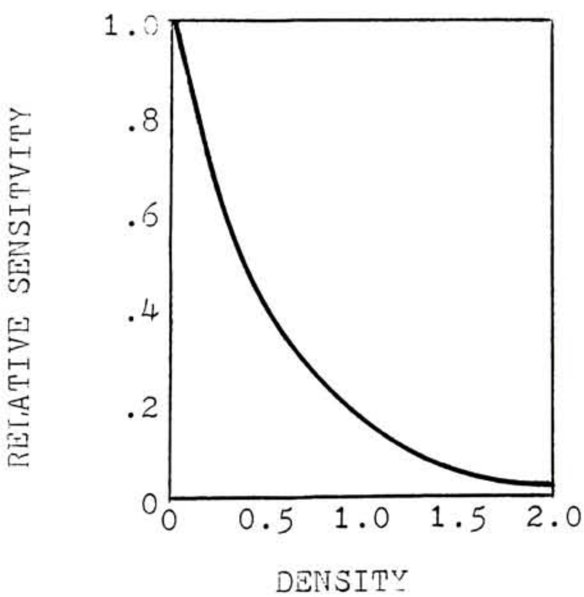

Fig.1. The empirically derived sensitivity function used in the Dooley and Shaw graininess algorithm.

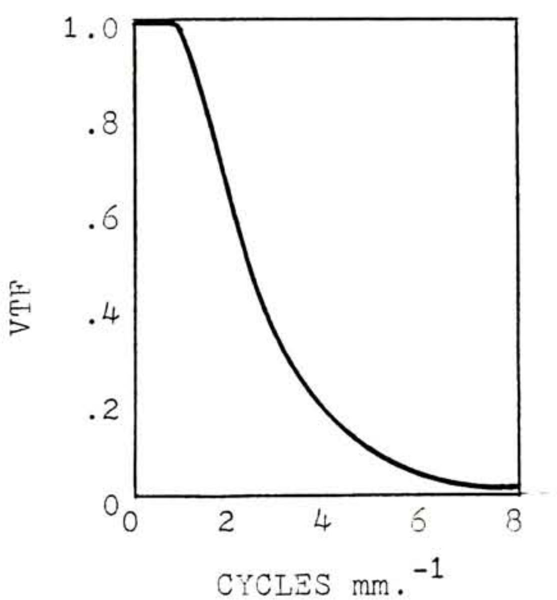

Fig.2. The visual transfer function used for the Dooley and Shaw graininess algorithm.

4. subjective testing

A "viewing booth" was constructed for use in the subjective testing and is shown in Fig.3. Standard fluorescent tubes provided constant illumination of approximately 1300 lux at the viewing plane. A numbered scale was divided into 100 intervals which provided a ranking of graininess between 0-100. The subjective testing of the graininess of the 23 density patches was done using a rank ordering technique with two anchors. Two of the density patches were used as anchors. The low-graininess anchor was defined as a graininess of 25 and the high-graininess anchor was defined as a graininess of 60. An observer was then given the remaining 21 patches and asked to order them along the graininess scale relative to the two anchors. The observer was instructed to base their evaluation solely on the graininess of the

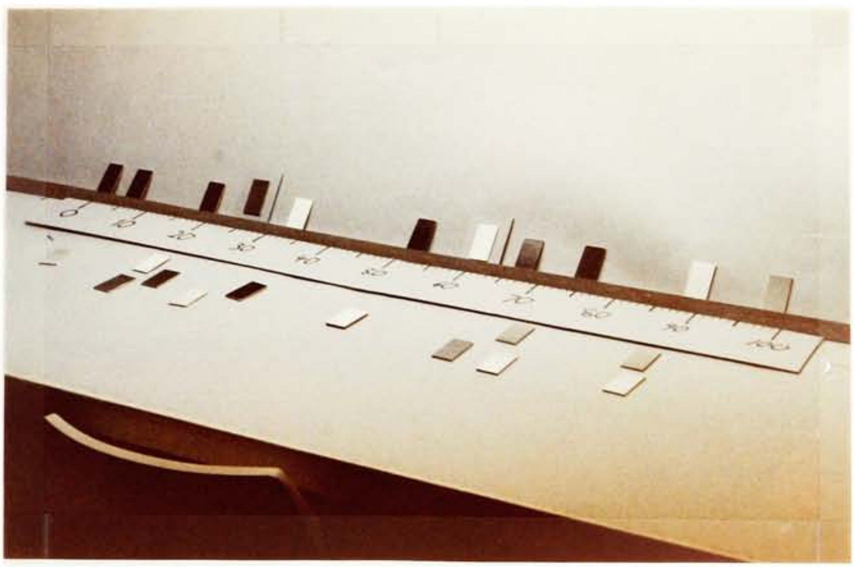

Fig.3. Viewing booth used for subjective testing.

patch, regardless of density, perceived image quality, or any physical defects including scratches, dust, pinholes, etc. The observer was then asked to assign a graininess value for each patch relative to its position on the scale. 28 observers were used in this experiment.

5. validation of algorithm

An ABSTAT[25] statistics software package was used to analyze the predicted graininess from the graininess algorithm and the judged graininess from the subjective testing. A regression was used to test the 23 density patches for a linear fit. A linear correlation was expected.

B. Experimental 2 -- test scenes

1. preparation of test scenes

Four scenes were photographed with each of the three film types, thus producing 12 test scenes. The film negatives were printed on Kodak Polycontrast Paper at 20X magnification. All processing was done according to manufacturer's recommendations. It was desired to use scenes that would produce differing histograms so that the graininess model could be thoroughly tested. The four scenes used in this investigation are shown in Appendix B.

2. scanning of test scenes

A reflection microdensitometer, similar to the one used to make the Wiener spectrum measurements, was used to scan the test scenes to generate density histograms. The microdensitometer scanned the test scenes using an aperture .1 inch X .1 inch, taking one reading every .1 inch. The number of readings was dependent on the size of the test scene. The histograms of the four test scenes printed from the Tri-X negatives are shown in Appendix C. The histograms of the same scenes, from the other films, are similar in distribution. Some differences, however, did occur due to contrast differences and also some histograms were shifted along the density axis due to print exposure variations. A histogram determined in this manner actually represents the fractional area occupied by each given density.

3. a model for predicting graininess

In mathematical terms, the predicted graininess for each scene is equal to the expected value of the graininess of the test scene. The expected value of a function of a random variable is defined as

$$E\left[g(x)\right] = \int_{-\infty}^{\infty} g(x)p(x)dx \tag{6}$$

where p(x) is the probability density function (PDF) of the random variable, and g(x) is the function of the random variable.

The probability estimate, p(x), has already been discussed. Such an estimate is determined from the density histograms established when scanning the test scenes. It now becomes necessary to define, for this study, the function g(x). As previously mentioned, one of the objectives of this investigation was to expand the use of the Dooley and

Shaw graininess algorithm for images of non-uniform density. The algorithm assigned graininess values to images of uniform density. If this was done for a wide range of uniform-density images, a function g(x) could be established, or in other words, a graininess vs. density curve could be produced. This, in fact, was the case. In addition to the density patches that were produced to verify the graininess algorithm, a much larger sample size was produced to generate graininess-density curves for each film type.

A graininess-density curve determined in this manner would be useful in calculating the graininess for a given density. If we wish to determine a graininess value from samples of varying levels of density, however, it seems reasonable to assume that the graininess will be "weighted" by the frequency of occurence of each measured density. It is then possible to develop a model whose predicted graininess, GS', is expressed as

$$GS' = \int_0^\infty GS(D)P(D)dD \tag{7}$$

where GS(D) is the graininess vs. density determined experimentally, and P(D) is the frequency of occurence, probability estimate, of a measured density in the test scene. The hypothesis to be tested is that this expected value should be proportional to the graininess that people perceive in the scenes.

4. subjective testing

The subjective testing of the graininess of the 12 test scenes was done using the same 0-100 graininess scale that was used for the density patches. The technique used for this testing was magnitude estimation with a single anchor. One of the 12 scenes was chosen as a reference and assigned a graininess value of 50. An observer was then given each of the remaining 11 scenes, one at a time, and asked to assign each scene a graininess value based on the graininess of the reference. The observer was instructed to base their evaluation solely on the graininess of the test scene, regardless of perceived image quality, or any physical defects including scratches, dust, pinholes, etc. The observer was allowed to look at all 12 of the scenes before the testing took place so that he/she could establish their own frame of reference. The same 28 observers were used in this experiment.

5. validation of graininess model

The ABSTAT statistics software package was again used to analyze the predicted graininess from the graininess model and the judged graininess from the subjective testing. Again, a linear correlation was expected, and a regression used to test the 12 test scenes for a linear fit.

III. Results

A. Uniform-density patches

The initial results were moderately sucessful. The judged graininess for the 23 density patches is plotted in Fig.4 as a function of predicted graininess. The linear correlation coefficient (r) between the judged and predicted graininess values was determined to be 0.83. It was apparent that the graininess algorithm was not accurately predicting the graininess in the test samples and that the largest errors were occuring at the higher densities. Because the largest errors occured at higher densities, it was theorized that the sensitivity function was not "weighting" the higher densities enough. It seemed appropriate that a modification to the sensitivity function

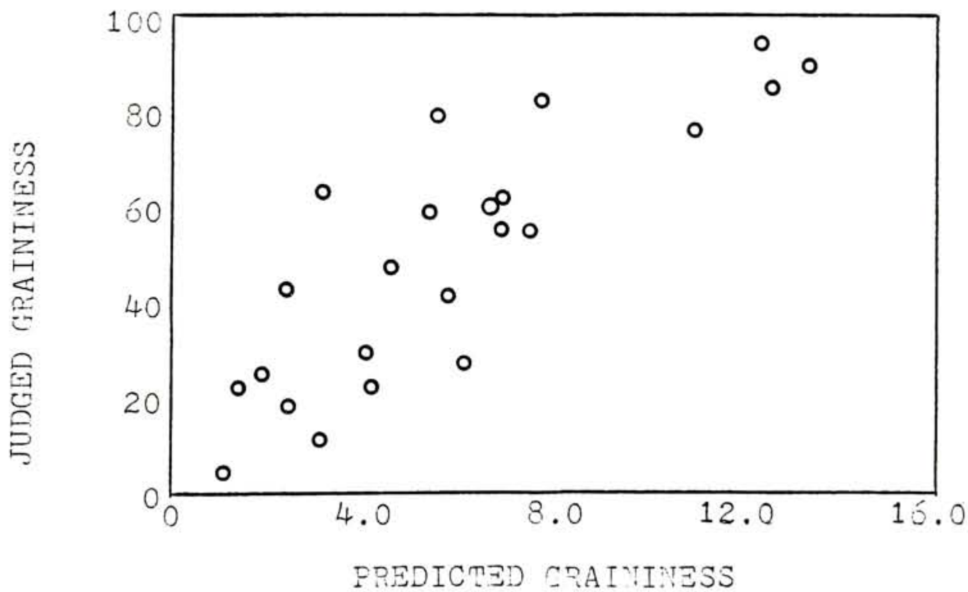

Fig.4. The judged graininess for the 23 density patches plotted as a function of predicted graininess (from Dooley and Shaw algorithm).

was needed.

The sensitivity function can be experimentally derived by substitution of judged graininess for predicted graininess in the graininess algorithm. Equation (5) can be rewritten as

$$S(d) = \frac{\overline{GS}}{I}$$

where $\overline{GS}$ is the judged graininess value, and I is the integral from equation (5). The value of S(d) was calculated for each density patch, plotted as a function of density, and fit with an exponential. This experimentally derived exponential, $e^{-1.4\bar{D}}$, has been plotted in Fig.5 along with the original function $e^{-1.8\bar{D}}$. It can be seen that the general

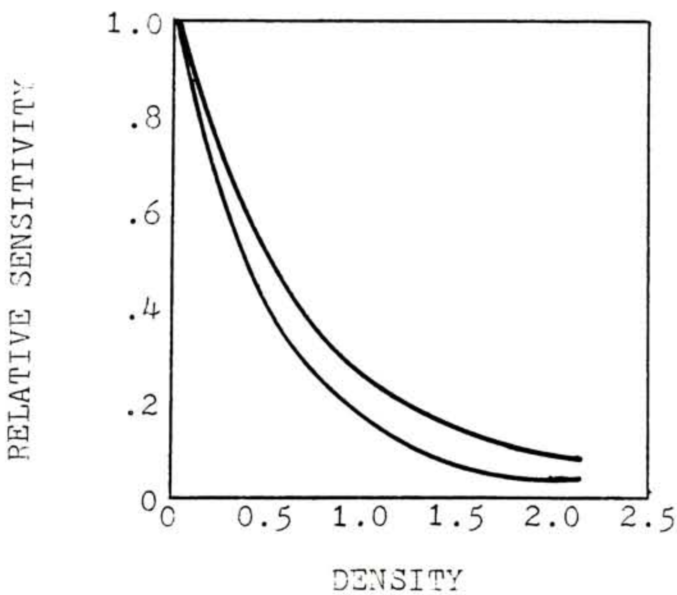

Fig.5. Sensitivity function used in the Dooley and Shaw algorithm (lower curve) and the sensitivity function determined in present study (upper curve).

shapes of the two curves are the same but the curve determined in this experiment, has a slightly higher weighting function, particularly at the higher densities. The modified graininess algorithm can be expressed as

$$\hat{GS} = e^{-1.4\bar{D}} \int_0^\infty \sqrt{WS(u)}\ VTF(u)du \qquad (8)$$

where $e^{-1.4\bar{D}}$ is the sensitivity function determined in this study. The predicted graininess was calculated for each of the 23 density patches using this algorithm and the judged graininess plotted as a function of predicted graininess (Fig.6). A linear correlation coefficient (r) of 0.91 was determined.

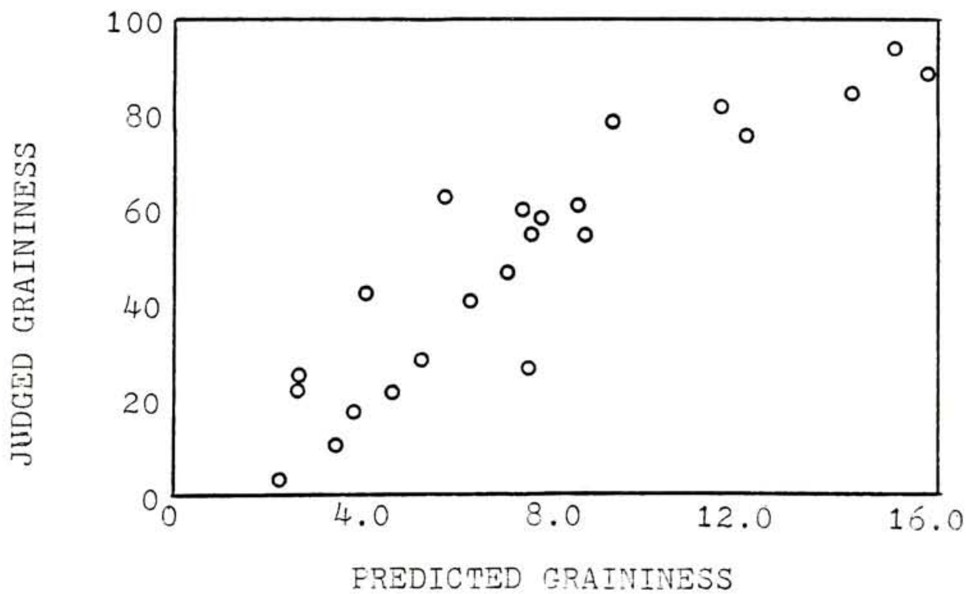

Fig.6. The judged graininess for the 23 density patches plotted as a function of predicted graininess (from algorithm developed in this study).

B. Test scenes

Graininess was calculated for a number of density patches using equation (8) and plotted as a function of density for each of the three film types (Fig.7). These curves are similar to what has been reported in the literature for the relationship between graininess and density.[26] The three curves were fit with a least squares polynomial regression for use in the calculation of the predicted graininess for the test scenes, equation (7). The relationship between the judged and predicted graininess for the 12 test scenes is shown in Fig.8. The linear correlation coefficient (r) for this relationship is 0.86.

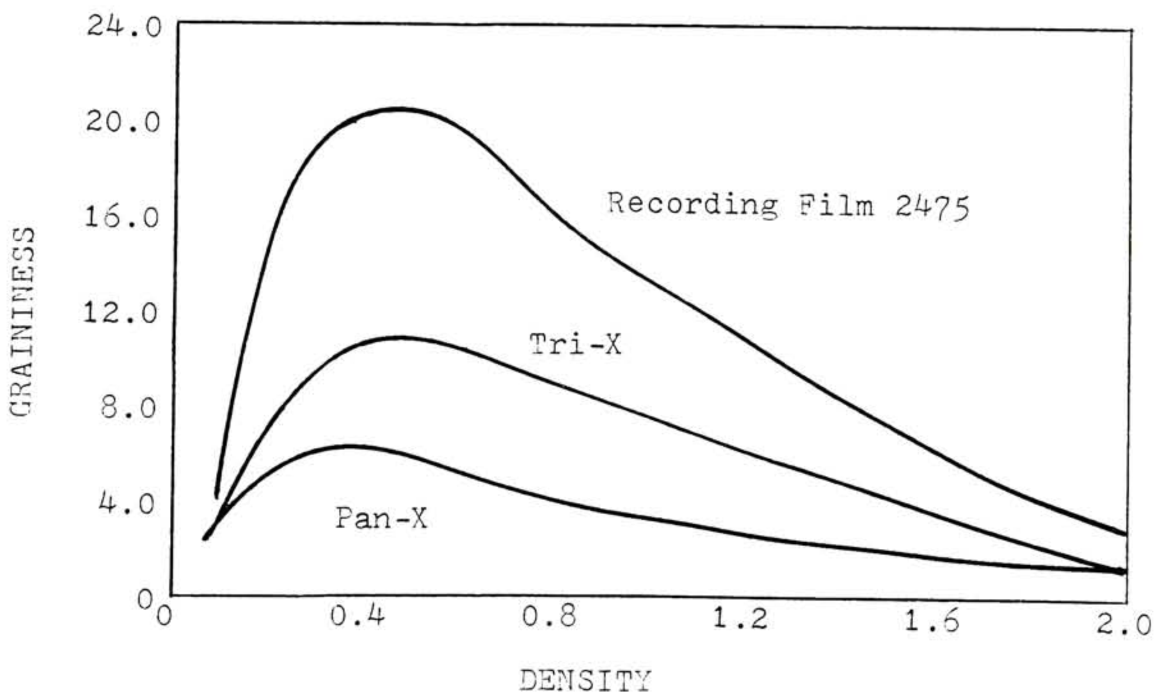

Fig.7. Graininess as a function of density for each film.

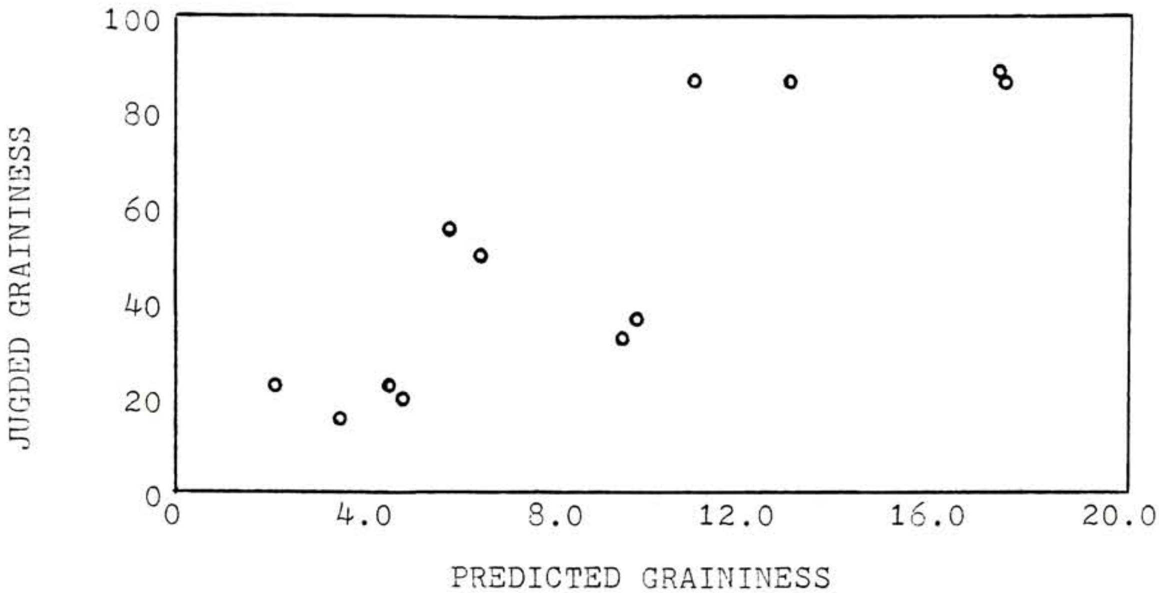

Fig.8. The judged graininess for the 12 test scenes plotted as a function of predicted graininess.

IV. Discussion

It seems necessary, at this point, to justify the modification of the sensitivity function, and hence the graininess algorithm. The procedure used to experimentally determine the sensitivity function is not original to this investigation. In fact, Dooley and Shaw used this procedure to determine the sensitivity function in Fig.1. The original sensitivity function used in their algorithm was based on a visual brightness response function. The Munsell Value scale was used to describe this brightness response function and the sensitivity function became a result of the relationship between Munsell Value and density. Using the Munsell Value-based sensitivity function, their results were satisfactory. Using the experimentally determined sensitivity function, their results were greatly improved. Both of the sensitivity functions were very similar, however, one carried a slightly different "weight" over the range in density. Dooley and Shaw theorized that the established Munsell Value scale need not be universally accepted and that if a slight variation produced more accurate results, the change was warranted.

For this study, the same argument can be used to justify the modification of the sensitivity function used by Dooley and Shaw. In addition, the inherent differences between electrophotography and silver-halide photography can explain differences that occur in quantitative or qualitative measurements. Therefore, if a slightly different sensitivity function is needed in silver-halide photography, its use is justified.

The results from the analysis of the test scenes was positive. The correlation was lower than that of the density patches but this was expected. It seems intuitively obvious that an observer would have more trouble judging the graininess in images of non-uniform density than in images of constant density. The major problem encountered in the model for predicting graininess was that people have a tendency to "peak pick". In other words, they choose an area, or areas, that exhibit the highest graininess and base their evaluation on that area. The observers were instructed to consider the entire image when making their evaluations, but it appears safe to assume that people do not integrate graininess when evaluating graininess in photographs. Developing a model that would predict graininess in photographs in terms of peak graininess would be an interesting area for further research.

V. Conclusions

The conclusion that is drawn from the results of this investigation is that the algorithm developed by Dooley and Shaw, with a slight modification, is valid for use in images of uniform density that exist in silver-halide photography. The concepts and implications are directly applicable, only a slight variation in how each density is "weighted" has changed. In addition, the modified algorithm can be used in developing a graininess model for predicting graininess in images of non-uniform density. This model has been proven successful in predicting the perception of graininess in complex photographic images.

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Appendix A.1.

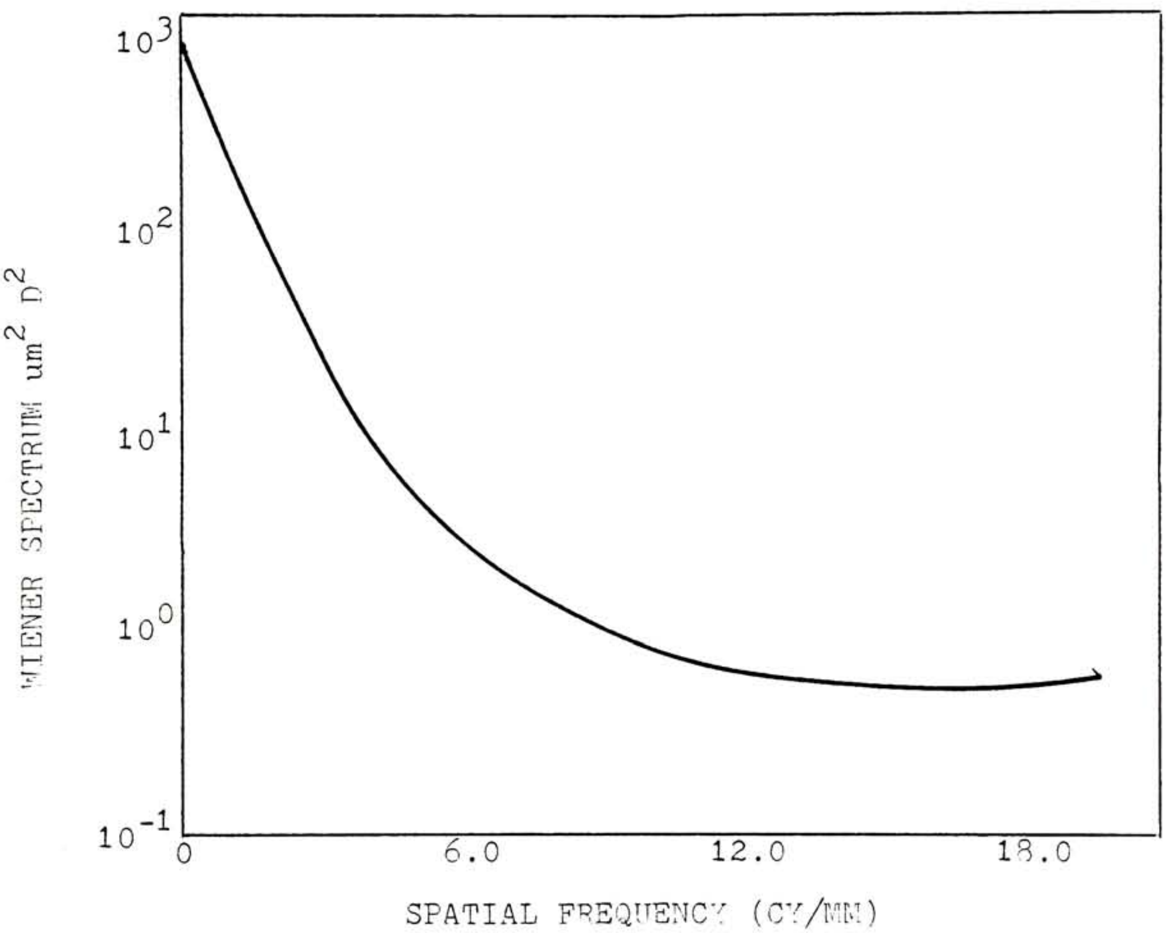


Fig.9. Wiener spectrum for one of the 23 density patches. The spectrum of the other patches were similar to this one.

Appendix A.2.

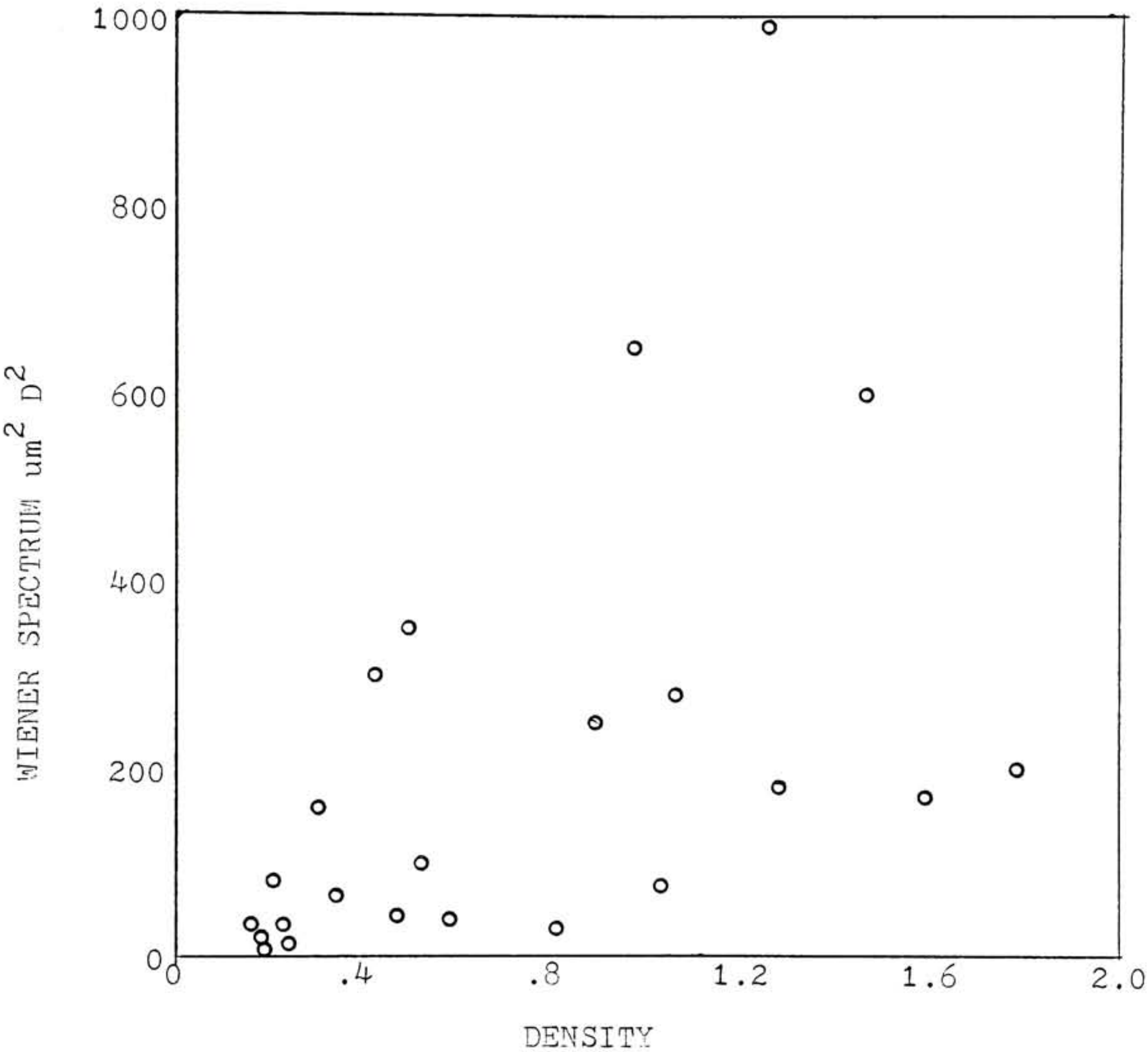
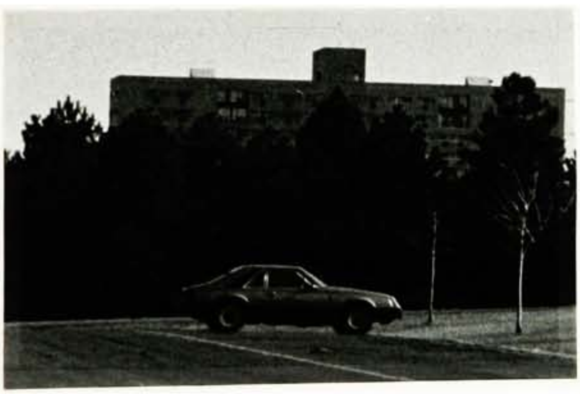


Fig.10. The low spatial-frequency Wiener spectrum value as a function of mean density for each of the 23 density patches.

Appendix B.

Scene 1

Scene 2



Scene 3

Scene 4

Appendix C.

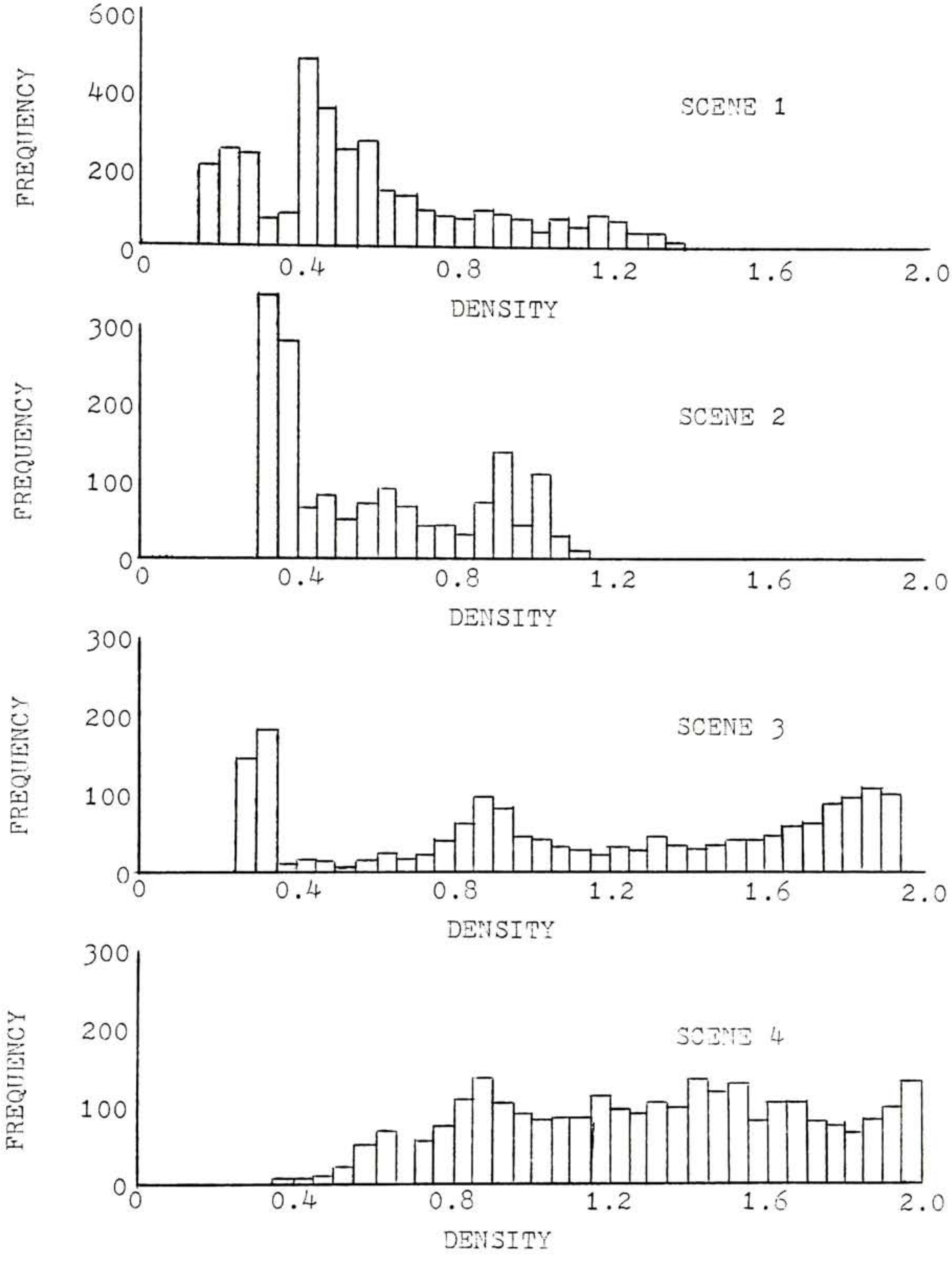


Fig.11. Emperically determined density histograms for each of the four test scenes from Tri-X negatives.

Vita

The author, a native of Rochester, New York, was a 1979 graduate of Greece Athena High School. He entered the Photo-Science program at Rochester Institute of Technology in the fall of that year. His educational interests turned towards image evaluation during his junior year, a resultant of which is this thesis. His career interests lie in the field of imaging science and at the time of this writing, he was considering job prospects in this field.